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for

**CONFIGURABLE ASIC MEMORY BIST CONTROLLER
EMPLOYING MULTIPLE STATE MACHINES**

by

Michael C. Dorsey

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Mary Paul
Mary Paul

CONFIGURABLE ASIC MEMORY BIST CONTROLLER EMPLOYING MULTIPLE STATE MACHINES

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention pertains to built-in self-testing ("BIST") of application specific integrated circuit ("ASIC") devices, and, more particularly, to a dual mode BIST controller.

2. DESCRIPTION OF THE RELATED ART

The evolution of computer chips typically spawns ever more complex integrated circuits. Manufacturers continually seek to fabricate more and smaller integrated circuit components in smaller areas. The effort pushes the abilities of technology in a number of areas including design, fabrication, and testing. In particular, as integrated circuits become more complex, they become more difficult to test, as do the computer chips, or "devices," into which they are fabricated.

The difficulty in testing integrated circuit devices affects not only the manufacturer. Frequently, a chip vendor will contract with a manufacturer to make chips on specification for them to sell. Just as the manufacturer wants to test the devices to make sure they meet applicable quality standards, the vendors want to make sure the devices they purchase meet the standards they set. This common concern has led the industry to develop several conventional approaches to testing integrated circuit devices.

One approach to testing integrated circuits is "built in self-testing," or "BIST." In BIST, in addition to "core" integrated circuits that provide the functionality of the device, the device includes integrated circuitry dedicated to testing. In this sense, the testing capability is "built-in" to the integrated circuit device. On receiving a predetermined signal, the BIST circuitry tests the core integrated circuitry and indicates whether it functions as designed. In this sense, the integrated circuit is self-testing in that it performs the test itself upon receipt of the externally generated test signal.

1 BIST comes in at least two variations. One is "memory" BIST, or "MBIST," and the
2 other is "logic" BIST, or "LBIST." The MBIST tests the memory components of the device
3 and the LBIST tests the logic on the device. An industry group called the Joint Test Action
4 Group ("JTAG") developed an industry standard for interfacing with integrated circuit
5 devices during tests. The JTAG standard is used with both variations of BIST. The
6 integrated circuit device is manufactured with a JTAG "tap controller." The device is then
7 tested in a live system or placed upon a chip tester. The live system or the chip tester
8 generates a JTAG BIST signal input to the JTAG tap controller, which then begins the BIST.
9 LBIST and MBIST can be used separately or in conjunction. The results of the BIST then
10 tell the operator (if in a live system) or the vendor or manufacturer (if in a chip tester)
11 whether and to what degree the device functions.

12 While BIST has many advantages and many uses, it also has some drawbacks. The
13 logic and wiring with which the BIST are implemented take up valuable "real estate" on the
14 die of the device. They also complicate the placement of device components and the routing
15 of the connections between them. One reason for this complication is that the logic and
16 circuitry implementing the BIST are distributed across the die. Another reason is that, during
17 the design process, the LBIST and the MBIST are designed as separate "modules," or black
18 boxes defined by their functions. Still another reason is that LBIST and MBIST operate in
19 different time domains, and require separate clock signals. LBIST is further complicated by
20 the fact that different parts of an ASIC typically operate at different frequencies, and signals
21 from one domain into another can cause timing violations invalidating the LBIST results.

SUMMARY OF THE INVENTION

22 The invention comprises, in its various aspects and embodiments, a technique for
23 performing a memory built-in self-test for an integrated circuit. The technique includes a
24 memory built-in self-test controller including a plurality of alternative memory built-in self-
25 test state machines and a memory built-in self-test engine operating a predetermined one of
26 the memory built-in self-test state machines. It also includes a method for performing a built-
27 in self-test on an integrated circuit device. The method includes externally resetting a
28 predetermined one of a plurality of memory state machines in a memory built-in self-test
29 controller; performing a memory built-in self-test utilizing the reset memory state machine;
30 and obtaining the results of the performed memory built-in self-test.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

FIG. 1 conceptually illustrates a dual mode BIST controller constructed and operated in accordance with the present invention in a block diagram of an application specific integrated circuit ("ASIC");

FIG. 2 depicts one particular embodiment of the LBIST domain of the dual mode BIST controller in **FIG. 1** in a block diagram;

FIG. 3 illustrates one particular embodiment of a state machine for the LBIST engine in the LBIST domain of **FIG. 2**;

FIG. 4 illustrates one particular embodiment of a multiple input signature register ("MISR") of the LBIST domain of **FIG. 2**, the contents of which is the LBIST signature;

FIG. 5 illustrates one particular embodiment of a register used in a pattern generator for the LBIST engine in the LBIST domain of **FIG. 2**;

FIG. 6 illustrates one particular embodiment of the MBIST domain of the of the dual mode BIST controller in **FIG. 1** in a block diagram;

FIG. 7 illustrates one particular embodiment of a MBIST signature register of the MBIST domain of **FIG. 2**, the contents of which is the MBIST signature in accordance with one aspect of the present invention;

FIG. 8 illustrates one particular embodiment of a state machine for an MBIST engine in the MBIST domain of **FIG. 2**; and

FIG. 9 illustrates the LBIST engine of **FIG. 1** and **FIG. 2** providing clock signals to other parts of the ASIC in **FIG. 1** in one particular embodiment of the invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed,

but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

5 Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort, even if complex and time-consuming, would be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

10 **FIG. 1** conceptually illustrates a dual mode built-in self-test ("BIST") controller 100 constructed and operated in accordance with the present invention. In the illustrated embodiment, the controller 100 comprises a logic BIST ("LBIST") engine 110, a memory BIST ("MBIST") engine 120, a LBIST signature 130, and a MBIST signature 140 separated into a LBIST domain 160 and a MBIST domain 170. Note that some embodiments may omit the MBIST signature 140 in accordance with conventional practice. The LBIST signature 130 and the MBIST signature 140 are the contents of memory elements of the BIST controller 100, such as registers, as is discussed further below.

25 The controller 100 comprises a portion of an integrated circuit device, *i.e.*, an application specific integrated circuit ("ASIC") 150. The ASIC 150 includes a testing interface 180, preferably a Joint Action Test Group ("JTAG") tap controller, through which the BIST of the dual mode BIST controller 100 can be invoked and through which the results may be returned in accordance with conventional practice. The ASIC 150 also includes one or more memory components 190, preferably synchronous random access memories ("SRAMs"), and combinatorial logic in a plurality of timing domains 195a-d that are tested by the BIST of the dual mode BIST controller 100.

30 The dual mode BIST controller 100 includes three frequency domains—one in the LBIST domain 160, one in the MBIST domain 170, and a third in which the signals from the

testing interface 180 operate. In one particular embodiment, the LBIST domain 160 operates on a 10 MHz clock, the MBIST domain 170 operates on a 75 MHz clock, and the third domain operates at a 10 MHz clock in accordance with the JTAG standard. In this particular embodiment, the 75 MHz clock is obtained by splitting the 150 MHz clock, as will be discussed further below, and the 10 MHz LBIST clock is generated based on the 10 MHz JTAG clock.

In one particular embodiment, the LBIST clock (not shown) operates at the lowest frequency of any of the logic involved in the LBIST. This includes the combinatorial logic under test, *e.g.*, the combinatorial logic in the timing domains 195a-d, or in the control logic, *i.e.*, the testing interface 180. Typically, the combinatorial logic of the ASIC core operates on several different frequencies defining different timing domains such as the timing domains 195a-d. These frequencies may be different from those employed by the control logic. Consider, for instance, an embodiment where the testing interface 180 operates at 10 MHz in accordance with the JTAG standard; the timing domain 195a operates at 150 MHz; and, the timing domains 195b-d operate at a variety of frequencies ranging from 66MHz to 133 MHz. The LBIST performed by the LBIST engine 110 will, in this particular implementation, be performed in all timing domains 195a-d at 10 MHz, which is the slowest frequency, to avoid timing errors. Thus, this particular embodiment employs a slow LBIST to preserve timing integrity across all the timing domains while reducing the number of LBIST engines 110 needed to perform the LBIST on any given ASIC. Note, however, that this is not necessary to the practice of the invention and some embodiments may replace this aspect with conventional techniques for addressing timing violations across timing domains.

Because the dual mode BIST controller 100 can perform both the LBIST and the MBIST, all BIST functionality can be centralized in one location. Thus, the BIST functionality of the ASIC 150 can be designed in a single module. Note that the manner in which the clock for the MBIST domain 170 is implemented facilitates this feature. Furthermore, the BIST functionality can usually be designed in the geographic center of the ASIC 150. This feature facilitates the placement of other components, *e.g.*, the memory components 190, the logic in the timing domains 195a-d, and the routing of connections. As will be appreciated by those skilled in the art having the benefit of this disclosure, the memory components 190 are typically large relative to other components of the ASIC 150.

5 Their placement therefore tends to dictate the location of other components, *e.g.*, the dual mode BIST controller 100, on the ASIC 150. Consequently, in some embodiments, the dual mode BIST controller 100 might not be located at the geographical center of the ASIC 150. However, most design techniques will result in the memory components being located at the corners of the ASIC 150, as shown in **FIG. 1**. The dual mode BIST controller 100 may therefore usually be geographically centralized.

10 One particular embodiment of the LBIST domain 160 is conceptually illustrated in **FIG. 2**. In this particular embodiment, the LBIST engine 110 comprises an LBIST state machine 210 and a pattern generator 230. The LBIST domain 160 also includes a multiple input signature register ("MISR") 220. The content of the MISR 220 is the LBIST signature 130 in **FIG. 1**. The pattern generator 230 is, more precisely, a pseudo random pattern generator ("PRPG"). In the illustrated embodiment, the LBIST engine 110 is externally configured by a CONFIGURATION signal with a vector count and a PRPG seed for the pattern generator 230. The LBIST engine 110 is configured by a 66-bit signal received through the testing interface 180 in which 32 bits contain the vector count and 33 bits contain the PRPG seed. Thus, the pattern generator 230 is programmable, as is the LBIST engine 110 as a whole. However, the invention is not so limited and other techniques may be employed for configuring the LBIST engine 110. For instance, these values may be hardcoded or hardwired in alternative embodiments.

15 20 In the illustrated embodiment, the LBIST engine 110 is also provided with the scan chain length in the ASIC 150. The value is, in this particular embodiment, hardwired to a value greater than the longest scan chain length in the ASIC 150. This value may be different for each implementation of the ASIC 150 and may be hard coded by the ASIC vendor. Furthermore, in some alternative embodiments, this value may be provided to the LBIST engine 110 through the testing interface 180.

25 30 Turning now to **FIG. 3**, the LBIST state machine 210 has five primary states: a reset state 310, an initialization state 320, a scan state 330, a step state 340, and a done state 350. The LBIST state machine 210 is reset, *i.e.*, transitions to the reset state 310, whenever an external reset signal is asserted regardless of which state in which it might be. On transition to the reset state 310, the MISR 220 and the pattern generator 230 are initialized. The LBIST

state machine 210 remains in the reset state 310 until the LBIST RUN signal is received, whereupon it transitions to the initiate state 320. In the initiate state 320, the LBIST initiates the various signals to be used in the LBIST. For instance, the COUNTER(S), COMPLETE, and ERROR signals, whose functions shall be discussed more fully below, are initialized. The LBIST state machine 210 then automatically transitions to the scan state 330 and begins to repeatedly cycle through the scan state 330 and the step state 340. Note that, in the early cycles, the scan state 340 flushes the scan chains (not shown) and the MISR 220 is not loaded, in the illustrated invention, until after the scan chains flush.

The scan state 330 and the step state 340, together, comprise the actual LBIST. The LBIST state machine 210 cycles through the scan state 330 and the step state 340 until reset by the external reset signal or until the LBIST is complete. The LBIST can be performed repeatedly without resetting through the external reset signal. Prior to entering the done state 350, the LBIST state machine 210 cycles through the scan state 330 and the step state 340 a number of times based on the vector count. As mentioned above, in the illustrated embodiment, the vector count is externally configured. The LBIST state machine 210 of the illustrated embodiments cycles through the scan state 330 and the step state 340 until the content of the pattern generator 230 is equal to the vector count. However, alternative embodiments may base the number of cycles on the vector count in alternative manners.

If the LBIST completes without being externally reset, the LBIST state machine 210 transitions to the done state 350. In the done state 350, the LBIST engine 110 provides a "BIST complete" indicator signal COMPLETE. The COMPLETE indicator signal also indicates that the results are "fresh," i.e., from the current LBIST and not from an old run. In accordance with one aspect of the present invention, the indicator signal COMPLETE sets a designated bit in the MISR 220 to indicate that the LBIST is complete in the LBIST signature 130. Thus, the LBIST signature 130 includes an indication of whether the LBIST is done. The LBIST engine 110 also provides an error signal ERROR, indicating the pattern generator 230 went to an "all zeros state," which is highly undesirable. Also in accordance with one aspect of the present invention, the ERROR signal sets a designated bit in the MISR 220 to indicate in the LBIST signature 130 that this error condition arose during the LBIST. Note that alternative embodiments of the present invention may omit one or both of the "done" and

"error" indications in the LBIST signature 130 should they choose not to implement these aspects of the present invention.

The MISR 220 is, in the illustrated embodiment, a 32-bit register shown in FIG. 4. The MISR 220 is initialized when the LBIST state machine 210 resets and shifts during the scans. The MISR 220 may be implemented using any techniques known to the art. However, as was mentioned above, in the illustrated embodiment, one bit, e.g., the bit B_{32} , is used to indicate that the LBIST is done/fresh and one bit, e.g., the bit B_{33} , is used to indicate that an error condition arose. Furthermore, in accordance with yet another aspect of the present invention, the done bit of the MISR 220, e.g., the bit B_{32} , is used to indicate that the LBIST signature 130 stored in the MISR 220 is new or valid, and not the result of a previous run. For instance, this bit may be cleared when the LBIST state machine 210 enters the reset stage 310 and the MISR 220 is initiated, and then set when the LBIST state machine 210 enters the done state 350. Note that the MISR 220 can be implemented using registers having sizes other than 32 bits. The logic pattern held in the bits B_{31} - B_0 in the MISR 220 can then be externally compared to a known pattern after the LBIST is done to establish pass/fail results.

The pattern generator 230 is implemented, in the illustrated embodiment, in a 31-bit linear feedback shift register ("LFSR"), shown in FIG. 5, such as is known to the art. the pattern generator 230 may be implemented using any suitable technique known to the art. However, in the illustrated embodiment, the pattern generator 230 is initialized to the externally configured PRPG seed when the LBIST state machine 210 enters the reset state 310. Selected outputs of the LFSR supply the scan pattern to the inputs of the scan chains (not shown) in a conventional fashion. During scan, the LFSR continuously shifts from the most significant bit ("MSB") B_{30} to the least significant bit ("LSB") B_0 .

In accordance with yet another aspect of the invention, the content of the LFSR with which the pattern generator 230 is implemented and the register with which the MISR 220 is implemented are generated using different primitive polynomials to prevent failures disguised by aliasing. The content of the LFSR in the illustrated embodiment is based on the 31-bit primitive polynomial $x^{31} + x^3 + 1$ and the content of the MISR 220 is based on the 32-bit primitive polynomial $x^{32} + x^{28} + x + 1$. If the pattern generator 230 enters an all zero state, the error indicator will be activated and stored in bit B_{33} of the MISR 220. In this particular

embodiment, the even outputs of the LFSR (bits B_{26} to B_0) supply the scan pattern to the inputs of the scan chains 1 to 23, respectively. The MISR 220 has inputs that EXCLUSIVE-OR into the odd register bits B_7 through B_{31} and bit B_0 during the scan operation. Alternative embodiments may omit this aspect of the invention, however.

5 The LBIST engine 110 provides two level sensitive scan device ("LSSD") clocks, shown in FIG. 9, to the level sensitive scan devices (not shown) in the core 900. Both of these clocks are normally low, but alternately pulse high when the LBIST state machine 210 is in the scan state 330. After the scan chains are flushed, the MISR 220 (shown in FIG. 2) collects the scan data. The LBIST engine 110 also outputs two step clocks LBIST_STEP_CLKC and LBST_STEP_STEPE. The step clock LBIST_STEP_CLKC actually comprises three signals LBIST_STEP_CLKC1, LBIST_STEP_CLKC2, and LBIST_STEP_CLKC3. The LBST_STEP_CLKC clock, normally high, enables the LBST_STEP_CLKC1 through to the core latches (not shown) via the core logic clock splitters (not shown) of the core 900. The LBST_STEP_CLKC2 is enabled by the LBST_STEP_CLKC clock through the clock splitters (not shown) of the low power register array ("LPRA") wrappers 905. The LBST_STEP_CLKC clock also enables the LBST_STEP_CLKC3 through the clock splitter (not shown) of the wrappers for the memory components 150, i.e., the SRAM wrappers 910.

10 09976707.101304
20
25 Clock control is technically not a function within LBIST. Vendor ASICS have a primary input pin (not shown) on which they receive a TEST_MODE signal from the test controller 915 through the testing interface 180. When this signal is high, the LBIST is completely inhibited from affecting operation of vendor chip testers. During vendor chip LSSD testing, this input is held high. During normal operation, TEST_MODE is low. A signal received through the testing interface 180, e.g., a LBST_SEL signal from a joint test access group ("JTAG") controller 920, determines if the LBIST can supply the scan clocks and step clocks. The LBST_SEL signal controls a multiplexer (not shown) between the system clock received through the testing interface 180 and the LBIST step clocks. It also controls multiplexers (not shown) between the LSSD clocks and the outputs of the clock splitters driven by the LBIST step clocks as discussed above.

30

In the illustrated embodiment, the LBIST runtime is a function of the vector count provided the LBIST engine 110 and the hardwired scan length value discussed above. The number of clock cycles can be computed as:

$$[(\text{vector count} \times (4 + (2 \times \text{scan length value}))) + 2]$$

The clock rate is determined by a clock provided through the testing interface 180, e.g., the JTAG TCK.

Turning now to **FIG. 6**, the MBIST domain 170, first shown in **FIG. 1**, includes the MBIST engine 120 and a MBIST signature register 605 whose content is the MBIST signature 140. The MBIST engine 120, comprises a series of alternative MBIST state machines 610—one of which drives a nested MBIST engine 620 in accordance with yet another aspect of the invention. In this particular embodiment, the nested MBIST engine 620 is provided by an ASIC vendor, and one of the MBIST state machines 610 is designed to operate with that particular vendor-supplied, nested MBIST engine 620. Indeed, each of the MBIST state machines 610 is designed to operate with one or more alternative vendor-supplied nested MBIST engines 620 that may be nested in the MBIST engine 120. The MBIST state machines 610 may also be modifiable to facilitate operation with vendor-supplied MBIST engines 620 that were not anticipated at the time the ASIC 150 was designed.

The MBIST engine 120 is therefore modifiable or configurable at the time the ASIC is implemented in a register transfer level ("RTL") specification to accommodate a variety of nested MBIST engines 620 that might be obtained from various vendors. As those in the art having the benefit of this disclosure will appreciate, the nested MBIST engine 620 and the MBIST state machines 610 are a predefined library elements in standard RTL applications software. The RTL specification for the ASIC 100 contains a logic wrapper (not shown) defining the inputs and outputs for the library elements that define which of the MBIST state machines 610 provides the input and output to the nested MBIST engine 620. The RTL specification is then synthesized into a gate-level implementation for the ASIC 100.

5 The illustrated embodiment is therefore versatile with respect to which vendor-supplied MBIST engines 620 may be used. However, such versatility may not be desired in all embodiments. Some embodiments of the present invention may therefore include only a single MBIST state machine 610. Or, the versatility may be incorporated into a single MBIST state machine 610 that is highly modifiable or configurable. The number of MBIST state machines 610 employed in any given embodiment will therefore be implementation specific.

10 In accordance with still another aspect of the present invention, the results of the MBIST on the memory components 190 are stored as the MBIST signature 140, shown in **FIG. 1**, within the MBIST signature register 605. The structure and function of the MBIST signature 140 are analogous to the structure and function of the LBIST signature 130. The MBIST signature register 140 is also a multiple input signature register, but its contents differ from the MISR 220, and so will be loaded differently. In this particular embodiment, paranoid checks and MBIST engine states are stored in the MBIST signature register 605 for debug purposes. One bit of the MBIST signature register 605, e.g., the bit B_{31} , shown in **FIG. 7**, of this register is a "done" bit. The done bit indicates if the MBIST is done and, hence, if the results stored are new or resulted from a previous run.

15 20 25 The nested MBIST engine 620 tests from one to sixteen memory components 190 (not shown) in parallel depending on the specification of the ASIC vendor. The dual mode BIST controller 100 has a separate clock domain for the MBIST engine 120 in which the 150 MHz system clock is halved and the MBIST engine 120 is driven with the resultant 75 MHz clock. The results of the tests on the SRAMs are stored in the MBIST signature register 605. Bit B_{31} of this register is the "done" bit. The done bit indicates if the results stored are new or resulted from a previous run. In this particular embodiment, paranoid checks and MBIST engine states are also stored in the MBIST signature register 605 for debug purposes.

30 Each of the MBIST state machines 610 has, as is shown in **FIG. 8**, five states: a reset state 810, an initialization state 820, a flush state 830, a test state 840, and a done state 850. The MBIST engine 120 is reset to the reset state 810 by asserting the external reset signal. Note that, in this particular embodiment, the same external reset signal resets both the LBIST engine 110 and the MBIST engine 120.

5 The MBIST state machine 610 transitions to the initialization state 820 upon receipt of a MBIST select signal and a MBIST run signal received through the testing interface 180. The initialization state 820 is followed by a flush and then the test patterns as the MBIST engine 120 cycles through the initialization state 820, flush state 830, and test state 840. This transition occurs upon the completion of initialization of components and signals in the MBIST domain. The flush state 830 continues until the memory components 190 are flushed and initialized them to a known state. The MBIST state machine 610 then transitions to the test state 840. The MBIST engine 120 drives a one direction test pattern bus (not shown) out to all memory components 190, and they drive the result back to the nested MBIST engine 620 on another direction test pattern bus. The results are stored in the MBIST signature register 605 as part of the MBIST signature 140. When the MBIST is completed, the MBIST state machine 610 transitions to the done state 850, signaling completion by setting the dedicated bit in the MBIST signature register 605 to indicate the MBIST is complete.

As was mentioned above, the nested MBIST engine 620 is, in the illustrated embodiment, a vendor-supplied MBIST engine such as vendors use in their testers. The states 810, 820, 830, 840, and 850 of the individual MBIST state machines 610 may be implemented in accordance with conventional practice. Furthermore, the operation of the MBIST state machines 610 will be implementation specific depending on the implementation of the nested MBIST engine 620.

25 More particularly, in the illustrated embodiment, the memory components 190 are SRAMs and the testing interface 180 is a JTAG tap ("JTTAP") implemented as is known in the art. The MBIST engine 120 is reset by asserting the external reset signal received through the testing interface 180. With the JTAG Tap (not shown) controller signals of MBST_SEL and MBST_RUN, the MBIST engine 120 is initialized. Initialization is followed by flush and then the test patterns as the MBIST engine 120 cycles through the initialization state 820, flush state 830, and test state 840. The flush state 830 occurs, in the illustrated embodiment, for 1024, 75 MHz cycles and initializes the SRAM to a known state. Flush state MUX gates (not shown) are hand-instantiated within the SRAM wrappers 910 to hold the SCAN_IN IO (on which the dual mode BIST controller 100 outputs scan patterns) to a 1'b0; the first and second scan clocks are both held to a 1'b1 as the SRAM is flushed to all

zeros. Watchdog timers (not shown) are part of paranoid logic in the MBIST engine 120 to prevent the nested MBIST engine 620 from free running or having any destructive effects during normal functionality. The MBIST engine 120 drives a one direction test pattern bus (not shown) out to all SRAMs, and the SRAMs drive the result back to the nested MBIST engine 620.

In operation, the ASIC 100 shown in **FIG. 1** may be placed on a vendor-supplied tester having a test controller 915 including a JTAG controller 920, shown in **FIG. 9**, typically with several other ASICs 100 (not shown). Alternatively, the ASIC 100 may be tested in a live system having a live system controller 925 including a JTAG controller 920. The MBIST engine 120 includes a MBIST state machine 610, shown in **FIG. 6**, designed for use with this particular vendor-supplied test controller 915. In the illustrated embodiment, the JTAG controller 920 employs JTAG protocols and testing hardware, and so the testing interface 180 is a JTAG controller. As was noted above, the LBIST and MBIST capabilities of the dual mode BIST controller 100 may be utilized separately or conjunctively. Furthermore, the LBIST and the MBIST may be performed in parallel or in serial. However, the following discussion will contemplate a conjunctive use in serial. It is nevertheless to be understood that only one or the other may be employed in alternative embodiments.

The JTAG controller 920, shown in **FIG. 9**, of the vendor-supplied test controller 915 or the live system controller 925 provides the configuration data including the vector count and the PRPG seed to the LBIST domain 160 through the testing interface 180. The testing interface 180, under the control of the JTAG controller 920, then supplies the external reset signal, shown in **FIG. 2** and **FIG. 6**, to the LBIST domain 160 and the MBIST domain 170. The LBIST state machine 210 and the MBIST state machine 610 then each transition to their respective reset states 310, 810.

The testing interface 180, again under control of the JTAG controller 920, generates the LBIST run signal, whereupon the LBIST state machine 320 transitions into the initiate state 320. The LBIST engine 110 then initiates as was discussed above. The LBIST state machine 110 then cycles through the scan and step states 330, 340 as discussed above until the LBIST is complete, *i.e.*, the value of the pattern generator 230 is equal to the configured vector count. As the LBIST is run, the results are stored in the MISR 220. Note that the

LBIST is run at the slowest frequency in the testing interface 180 and the logic core 900, such that the results stored in the MISR 220 are free from errors that would otherwise arise from timing violations. When the LBIST is complete, the LBIST state machine 210 transitions to the done state 350. The LBIST engine 110 then generates a "complete" signal that sets a bit in the MISR 220 to indicate that the LBIST has successfully completed. If, for some reason, the pattern generator 230 goes to all zeroes, the error signal is instead generated and the LBIST aborted.

The testing interface 180 then generates the MBIST run and MBIST select signals, whereupon the MBIST state machine 610 transitions to the initialize state 820. The MBIST engine 120 initializes its components and signals as was discussed above. The MBIST state machine 610 then cycles through the flush and test states 830, 840 as discussed above using the nested MBIST engine 620. As the MBIST is run, the results of the paranoid checks and the MBIST engine states are stored in the MBIST signature register 605. When the MBIST is complete, the MBIST state machine 610 transitions to the done state 850, whereupon the MBIST engine 120 generates the complete signal, which sets a done bit in the MBIST signature register 605.

The dual mode BIST controller 100 permits all this functionality to be designed into a single module of the ASIC 150. This further facilitates the placement of other ASIC components and the wiring between them. The dual mode BIST controller 100 also permits the use of multiple clock domains in the same module. Because the results of both the LBIST and the MBIST are stored, the system controller 925 in the live system or the vendor-supplied test controller 915 can read out the results of the tests through the testing interface 180.

This concludes the detailed description. The particular embodiments disclosed above are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.